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To: Dr. D. Mills
Director of Research

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PROGRAMMING AND ERASURE OF 2732A EPROMs

J.D. Bruce

This report describes the programming and erasure characteristics of the Intel 2732A EPROMs used in the OH180 and PALC programmable controllers. Also included is a discussion of the data retention time and the radiation susceptibility of EPROMs.

1. INTRODUCTION

The Electronics and Instrumentation Section has designed a number of microprocessor-based systems using Intel 2732A UV-erasable programmable read-only memories (EPROM). These systems include the OH180 programmable controller used at Darlington NGS and the Programmable Auxiliary Logic Controller (PALC). Recently, a number of questions were asked by Darlington NGS personnel regarding the programming, erasing, care and handling of the EPROM devices. These questions were answered in a memo to Mr. L.E. Crossley/1/. The present report was written to provide a summary of the answers for other EPROM users and a list of the reference material used. Also, the appendix contains descriptions of experiments carried out on a number of 2732A EPROMs. The experimental results illustrate a number of EPROM characteristics and can be used as a basis for more detailed investigations if the need arises.

It should be noted that this report applies specifically to Intel 2732A EPROMs. Other types of EPROMs, or 2732A EPROMs manufactured by other companies, may have different programming algorithms or erasure characteristics. Users of EPROMs other than the Intel 2732A should refer to the manufacturer's literature for the proper procedures.

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2. PROGRAMMING CHARACTERISTICS OF 2732A EPROMs

When the 2732A EPROM is received from the factory, as well as after it has been erased, all data bits are in the '1' state. Programming a bit changes its state from '1' to '0'. The 2732A EPROM is programmed by setting the correct address and data on the address and data pins, raising the voltage on the programming voltage pin to 21 volts and applying a 50 ms active-low pulse to the chip enable input. Since the 2732A EPROM has 4096 locations to be programmed, the total programming time is 3.4 minutes. The programming requirements are given in detail in reference/2/.

3. ERASURE CHARACTERISTICS

The recommended erasure procedure for the 2732A EPROM is to expose the device to short-wave ultraviolet (UV) light with a wavelength of 253.7 nm. The minimum integrated dose (UV intensity x exposure time) for erasure is 15 W·seconds/cm^2/2/.

A number of EPROM erasing units are available. The recommended erasure time can be calculated from the manufacturer's irradiance specification. For example, the unit used in our lab is the model "UVS-54T" manufactured by Ultra-Violet Products, Inc. of San Gabriel, California. This unit produces an irradiance of 7500 uW/cm^2 on the EPROMs. Therefore, the recommended erasure time using this eraser is approximately 15/0.0075 seconds or 33.3 minutes.

The 2732A EPROM contents will appear to be erased long before the recommended erasure time is reached. In a recent experiment, a properly programmed EPROM appeared to be erased after only 80 seconds. See Experiment 2 in the Appendix for details. However, the use of less than the recommended erasure time may result in marginally erased EPROM locations. There is no practical way to determine how well erased the EPROM is.

When erasing EPROMs, the entire die (visible through the window) should be exposed to the UV light. Also, the EPROM window should be sufficiently clean to allow the UV light through. Dirt or residue from label adhesives could cast shadows on the die, resulting in incomplete erasure. An acceptable way of deciding whether the window is clean enough for the UV light is to inspect (by eye) for visible specks, dirt, grease or fingerprints. If none are visible, the window can be assumed sufficiently clean.

The eraser manufacturer's operating and maintenance procedures should be followed to ensure proper erasure. In addition, the UV light intensity should be measured periodically with a suitable UV radiometer. If the UV intensity has decreased significantly, the tube should be replaced or the erasing time increased. UV radiometers are available from a number of sources, including

Ultra-Violet Products, Inc. They recommend the use of their UVX Radiometer or the J-225 Short Wave UV Meter to measure the UV intensity of our UVS-54T EPROM eraser. It should be noted that we have not tested either of these meters, and therefore cannot make recommendations regarding their use.

Anyone using the ultraviolet eraser should be aware of the hazards associated with short wave UV light. Short wave UV light can quickly sunburn unprotected eyes and skin. Many UV erasers now available are equipped with safety interlocks that will not allow the light to be turned on until it is safe to do so. However, older erasers, such as our UVS-54T, do not include interlocks so the operator must proceed with caution to avoid injury.

EPROM erasure begins to occur when the EPROM is exposed to light with wavelengths shorter than about 400 nm (short wave ultraviolet). Sunlight and certain types of fluorescent lights may contain wavelengths in this range. Intel estimates that constant exposure to room level fluorescent lights could erase a 2732A EPROM in approximately three years and that direct sunlight could cause erasure in approximately one week/2/.

In a recent experiment using a programmed EPROM located two inches from a standard office-type overhead fluorescent lamp, some erasures were observed after six months. Intel recommends that 2732A windows be covered with opaque labels if they are exposed to fluorescent light or sunlight. Presumably, this advice also applies to any other type of light containing wavelengths shorter than 400 nm.

4. DETECTION OF MARGINALLY PROGRAMMED AND ERASED EPROMs

Several experiments were carried out to illustrate the programming and erasure characteristics of the 2732A EPROMs. Full details of these experiments are given in the appendix. Experiment 3 indicates that marginally programmed EPROM locations appear to be erased faster. For example, locations programmed with the normal 21.0 V, 50 ms programming pulses appeared to be erased after 60 seconds, while locations programmed with shorter (1 ms) pulses appeared to be erased after 50 seconds.

The conclusions of Experiment 3 could conceivably be used as a basis for program margin testing. However, the results shown are based on tests of a very small number of EPROMs. Extensive further testing would be required to determine if the erasure characteristics are consistent for a large number of EPROMs from different batches. In addition, a margin test of this kind could only be used on a sample basis because the test destroys the EPROM contents.

Since there is no practical way to determine if an EPROM is marginally programmed or marginally erased, the EPROM should be programmed and erased with properly set up and calibrated equipment.

5. RETENTION OF STORED PROGRAM

Intel data sheets do not specify the data retention time for programmed 2732A EPROMs. However, various statements in references/3/ and /4/ indicate that the minimum data retention time is "greater than twenty years". Data given in various other references indicate that time-related data loss has not in fact been observed at all, even under accelerated aging tests, under conditions equivalent to over a million years at 70°C/3/,/5/. The general conclusion arising from the literature available to us is that EPROMs will store their data for a much longer time than the normal service life of the equipment using the EPROMs.

6. RADIATION SUSCEPTIBILITY OF PROGRAMMED EPROMs

The type of radiation most harmful to the stored program in an EPROM is short wave ultraviolet light as described previously. Visible light, such as sunlight or fluorescent light, can cause erasure if it contains UV components. However, provided the EPROM windows are covered with a suitable opaque sticker, the effects of visible light can be ignored.

Low level x-ray or gamma ray fields are not considered to be a problem with EPROMs because the absorption cross-sections of the photons in silicon are quite small/6/.

Single ionizing events due to cosmic rays, alpha particles or beta particles cannot cause spurious erasures because not enough charge is created to neutralize the charge on the EPROM's floating gate/3/. The cumulative effect of such ionizing events is not described in the literature but is apparently not a problem for normal working environments. We found no references in the literature dealing with the effects of neutron fluxes on the data retention of EPROMs.

Further research is recommended if the EPROMs are to be used in high-radiation environments.

7. CONCLUSION

This report summarizes the information available to us regarding the programming, erasure and data retention of Intel 2732A EPROMs. Three experiments were carried out to illustrate EPROM characteristics. No practical method of testing the erase and programming margins of 2732A EPROMs was found. Therefore, it is recommended that the EPROM programming and erasing equipment be properly set up and calibrated and that the EPROM manufacturer's recommended programming and erasure procedures be followed.

Approved by:

A.F. Baljet
Manager
Electrical Research Department

Submitted by:

J.D. Bruce
Engineer
Electronics and Instrumentation Section

Reviewed by:

R.D. Brown
Supervising Engineer
Electronics and Instrumentation Section

JDB:lAg

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2. Memory Components Handbook, Intel Corp, 1985, pp 4-1 to 4-7 (2732A Spec Sheet).

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4. "Intel 2716 16K UV Erasable PROM", Reliability Report RR-19, Intel Corp, 1979.

5. N.R. Mielke, "New EPROM Data Loss Mechanisms", Proceedings of International Reliability Physics Symposium 21 (1983), p 106.

6. J.M. Caywood and B.L. Prickett, "Radiation-Induced Soft Errors and Floating Gate Memories", Proceedings of International Reliability Physics Symposium 21 (1983), p 167.

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8. Components Quality/Reliability Handbook, Intel Corporation, 1985.

APPENDIX

This appendix describes several experiments carried out on 2732A EPROMs. The experimental results illustrate a number of EPROM characteristics and can be used as a basis for future investigations if the need arises.

The following equipment was used for the experiments:

1. Hewlett-Packard HP64000 microprocessor development system.

   The HP64000 work station used for the experiments consisted of a 64100A mainframe, a 64501A EPROM programmer and a 64509A programmer module.

   The EPROM programmer was used to program some of the EPROMs used and to print EPROM contents. The programming voltage was 21.0 $\pm$ 0.5 V and the programming pulse width was 49.0 $\pm$ 1.0 ms.

2. OH180 Programming Station.

   The OH180 Programming Station and EPROM Programmer were used to program EPROMs using non-standard programming voltages and pulse widths. This equipment was used because the programming voltage and pulse width were easily adjusted.

3. Ultra-Violet Products, Inc. model UVS-54T EPROM eraser (Lab number 3463).

   The ultra-violet intensity of the eraser was not measured.

4. Tektronix 468 Digital Oscilloscope (Lab number 3923).

   The Tek 468 was used to measure the programming voltages and pulse widths.

Three new Intel D2732A-2 EPROMs were used for the experiments. Before the first use, and after each experiment, the EPROMs were erased for at least one hour to ensure complete erasure.

EXPERIMENT 1: EPROM PROGRAMMING

Purpose

Determine the effects of reduced programming voltage on the 2732A EPROM.

Procedure

1. Adjust the EPROM programmer to yield a 1 ms programming pulse.

2. Adjust the EPROM programmer to provide the desired programming voltage. For each programming voltage, repetitively program several EPROM locations with '0' and record the number of programming cycles required to program the first bit and the last bit in each location.

3. Repeat step 2 for each programming voltage.

Results

Results are shown for four EPROM locations for each programming voltage.

Programming Voltage (± 0.2 V)	Number of 1 ms Pulses Required to Program First Bit	Last Bit
15.0	16,14,21,18	28,35,31,26
16.0	4,3,4,4	6,5,6,5
17.0	1,1,2,1	2,2,2,2
18.0	1,1,1,1	1,1,1,1
19.0	1,1,1,1	1,1,1,1
20.0	1,1,1,1	1,1,1,1
21.0	1,1,1,1	1,1,1,1

CONCLUSIONS

1. When the programming voltage is lowered, it becomes more difficult to program an EPROM location.

2. The lowest programming voltage capable of programming a location in 1 ms is 18.0 V. Note that the location is marginally programmed and would not be guaranteed to retain the data.

EXPERIMENT 2: EPROM ERASURE

Purpose

Determine the time required to marginally erase a 2732A EPROM.

Procedure

1. Program all bits of a 2732A EPROM to '0' using the normal 21.0 V, 50 ms programming algorithm.

2. Turn on the EPROM eraser and allow it to warm up for five minutes. This allows the tube to reach its normal operating temperature.

3. Place the EPROM in the eraser and erase for ten seconds.

4. Remove the EPROM and print the contents of locations 0 to OFFH. This gives a total of 2048 bits.

5. Repeat steps 3 and 4 until all EPROM bits are '1'.

Results

Erase Time (seconds)	Bits Erased	% Erased
0	0	0
10	0	0
20	0	0
30	0	0
40	0	0
50	0	0
60	35	1.7
70	2038	99.5
80	2048	100.0

CONCLUSIONS

1. The first transition from programmed ('0') to erased ('1') occurred before 60 seconds of erasure.

2. The last transition from programmed ('0') to erased ('1') occurred before 80 seconds of erasure.

Note that locations erased for such short times may be marginally erased and would not be guaranteed to stay erased.

EXPERIMENT 3: ERASING MARGINALLY PROGRAMMED EPROMs

Purpose

Determine the time required to marginally erase a 2732A EPROM programmed with different programming algorithms. (This is a combination of experiments 1 and 2.)

Procedure

Apply the procedure of experiment 2 to an EPROM created by experiment 1, with the following exceptions:

1. Skip step 1 of experiment 2.

2. In step 3, erase for five seconds at a time rather than ten seconds.

Results

Programming Conditions	Time in Seconds Required to Erase First Bit	Last Bit
18.0 V, 1 ms	15	40
19.0 V, 1 ms	25	30
20.0 V, 1 ms	30	35
21.0 V, 1 ms	40	50
21.0 V, 50 ms	50	60
21.0 V, 100 ms	50	60

CONCLUSIONS

1. EPROM locations are easier to erase when they are not fully programmed.

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